Productivity and Plant Capacity Enhancement of an Automobile Industry using Flexible Manufacturing Technologies

A

Synopsis

Submitted in partial fulfillment for the requirements of

Doctor of Philosophy

In

Mechanical Engineering

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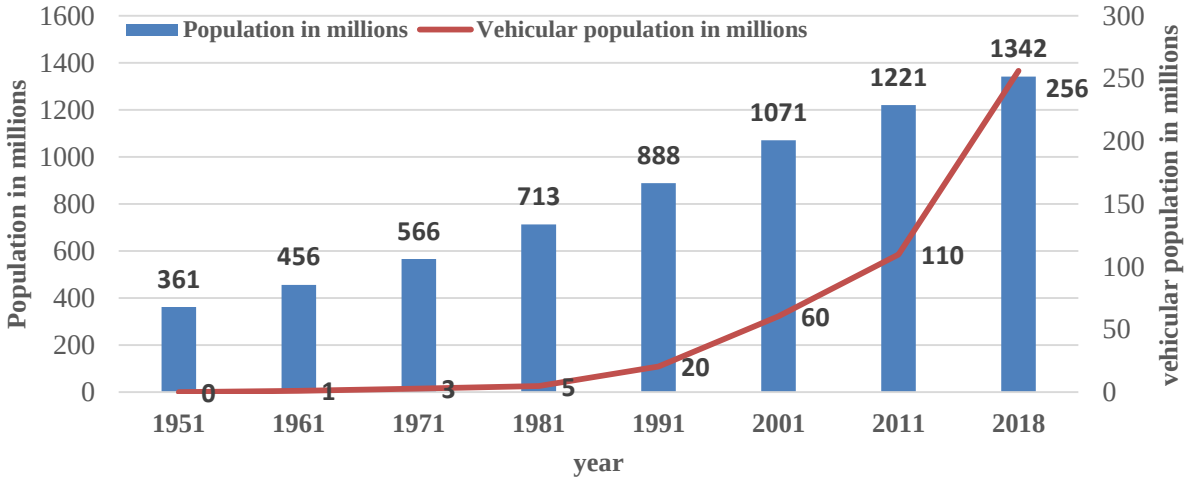
2020

Chapter 1: Introduction

Transportation has become life force in this century. It plays a major role in every important area of our life like education, business, security and improving quality of human life. Rapidly growing population of developing nations such as India, China and Brazil has made research and development in all aspects of transportation system highly imperative.

The Indian Automobile Industry is one of the largest, most diverse and least planned transport sectors in the world. The 21st Century brought rapid growth to India; the passenger car industry has benefited most in the transportation sector. As of 2018, India is home to 256 million passenger vehicles, making India the fastest growing Automobile market in the world. According to **the Society of Indian Automobile Manufacturers** annual vehicle sales are projected to increase at a rate of 9 million per year by 2020. By 2050, the country is expected to have more than 611 million vehicles on the nation's road.

Graph 1: Change in Population and Vehicular Population



The above graph [1-10] is showing the growth in population and vehicular population from 1951 to 2018. Rapid growth is seen after 1983, when Maruti started its production and after 1991 when international Original Equipment Manufacturers (OEMs) started to appear in the Indian market.

Automobile industry engaged in manufacturing of four wheelers vehicle in India is facing many challenges like high level of competition and ever increasing competitive pressure. Increase in demand resulted in the need of business improvement in all aspects of manufacturing, continuous improvement tools are used in all industries engaged in automobile manufacturing. In present day manufacturing there is a strong need of flexible manufacturing techniques to enhance the productivity of plant.

1.1. Factors Affecting Productivity

There are varieties of factors which can affect productivity, both positively and negatively as listed below. Some factors can be controlled and some cannot be controlled due to natural restrictions.

1. Capital investments in production
2. Capital investments in technology
3. Economy of scale
4. Technological changes
5. Work methods
6. Procedures
7. Systems
8. Quality of products

1.2. Techniques for Measurement of Productivity

Productivity has been demarcated as the ratio of output to input**.** Growth in productivity means increase in output that is equivalently superior to intensification in input.

Productivity may be measured either on a joint basis or specific basis. On collective basis, output is allied with all inputs taken (added) together. This is termed as total productivity. On individual basis, yield is associated with any one of the input feature and this is called as partial productivity or factor productivity.

$$\boldsymbol{Total\ productivity\ index\ = Total\ Output/Total\ Input}$$

Total Output= $Total\ production\ of\ goods\ and\ services$

Total Input= *Labour + Material + Capital + Energy*

This index measures the productivity of the whole organization with utilizing all the resources. It is a mode of assessing efficiency of entire plant or firm.

It has been said that the challenges of productivity has become a challenge of measurement. Productivity is tough to measure and can only be measured indirectly, that is, by measuring added variables and then calculating productivity from them. This struggle in measurement stems from the element that inputs and outputs are not only difficult to define but are also hard to enumerate.

Any productivity measurement scheme should yield some kind of general index of productivity. A keen measurement program associates productivity measurement into an overall assessment of performance. This type of system should be agile in order to accommodate changes in goals and strategies over time. It should also have the capability to aggregate the measurement systems of different components into a single system and be able to link productivity across diverse units.

Experts have quoted the need for a measurement program that stretches an equal weight to quality as well as productivity. If quality is encompassed in the ratio, output may have to be demarcated as something like the number of defect-free units of production or the quantity of units which meet client potentials or necessities. Therefore, it is very much crucial to understand different techniques of measuring the productivity and its improvement. In practice, there are numerous productivity improvement techniques. Significant techniques for measurement of productivity are discussed briefly as follows:

1.2.1 Productivity Improvement Indices

Factor productivity or partial productivity indices are of the following types:-

(i) **Technician productivity:** The significant role in any production planning is that the planned amount of work must be accomplished over a period of time. Technician productivity hinge upon how technicians are used. Worker productivity can be higher or lesser depending on factors like

accessibility of work load, material, working tools, availability of power, work effectiveness, level of enthusiasm, level of training, level of working condition (comfortable or poor) etc. Technician productivity can be measured in terms of hours or money.

(ii) **Material productivity:** Production system converts raw material into complete product with the help of mechanical processes. Material productivity shows vital role in cost of production. Material productivity is governed by how material is effectively consumed in its conversion into finished product. Material productivity depends upon % of rejection, creation of scrap, level of spoilage, obsolescence, work wastage etc.

(iii) **Machine Productivity:** Productivity of machine is subjected to availability of raw material, power, skill of workers, machine arrangement etc.

(iv) **Capital productivity:** For any production set-up, services of machines, tools, land etc., are vital and investment is needed for such assets. Any massive venture is locked in assets. Their effective consumption is completely necessary. Capital productivity depends on how successfully assets are consumed. Decision making plays a pivotal role in replacement of fixed assets. Maintenance cost is lowered by early replacement of fixed assets but on same side it requires capital expenses. Instead of, late replacement of fixed resources improves ratio of production to capital expenses, but it increases maintenance cost. Therefore proper balance is required. Organizations spend large amount (direct expenditure) for assets like direct material, direct wages, land, building, equipment etc., but a production system suffers a lot of direct expenditure like salaries of manpower employed in planning, store keeping, record keeping, inspection, labour used for material movement, good housekeeping, cleaning etc.

1.2.2 Japanese Productivity Improvement Techniques

Japan established number of productivity improvement practices after World War II .The Toyota Production System (TPS) covers the following productivity enhancement techniques [11]. Taiichi Ohno developed the Toyota Production System (TPS) after World War II. Some of the selected Japanese

Productivity Improvement techniques are presented in this section as below. Some of the Japanese Productivity improvement techniques are as follows:

(a) JIDOKA

(b) HEIJUNKA

(c) KAIZEN

(d) Five Ss of Housekeeping:

(e) Muda elimination

(f) Poka-Yoke

(g) SMED

(h) Total Productive maintenance (TPM)

(i) Just-In-Time

(j) Kanban

(k) Process Oriented Management (POM)

(l) Work Standards

(m) The PDCA/SDCA Cycle

(n) Suggestion Systems

1.2.3 Work Study as a Productivity Improvement Technique

Work study is a tool to achieve higher productivity. Human work, method of doing work and standard of performance are directly related with it. Technology, agility and production efficiency decide the survival of any organization in the market. The work is divided into small segments and then studied to rearrange it to get study of greater efficiency at low cost. Study of work measurement and method helps in investigation efficiency and economy to improve productivity. Further International Labor Organization (ILO) states that cost of process can be minimized by work study. It can be achieved either by designing the work for high productivity or by improving productivity in existing work through improvements in current methods by reducing ineffective and wasted time. It can directly be used to increase the productivity.

Various factors can affect the enterprises of productivity, such as Labor, Material, Land, Machine, Capital, Technology, product and Management. Developing new process and installing modern plant and equipment is one of the effective ways of raising the productivity in long run. But this approach requires heavy capital investment. It shows that there is positive (direct) association between work study and productivity enhancement. Work study technique comprises of eight phases as illustrated in Figure.1

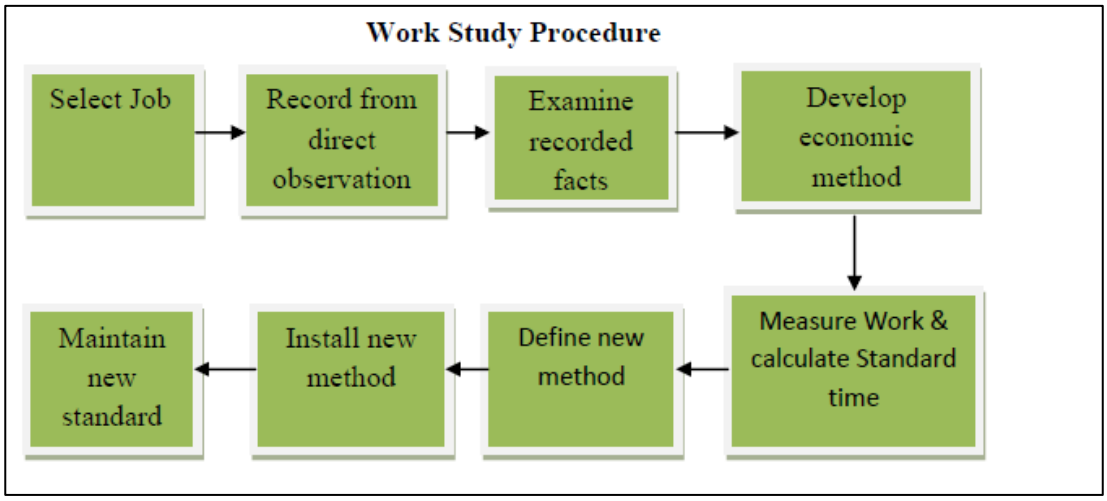


Figure 1: Work Study Method

Source: International Labor Organization (ILO), Introduction to Work Study, Universal Publishing Corporation, India

Chapter II: Literature Review

To meet increasing demand of market many automobile players are expending their companies or focusing to improve productivity without capital investment.

Weld, Paint and vehicle assembly are the main workshops to manufacture a four wheeler. These may be bottleneck for different players. Various methods are applied to increase efficiency of an automatic welding workshop in which spot welding is done by robotic manipulators.

Approximately 8% of total energy in production is consumed in spot welding process of an automobile industry [12]. The process comprises of logging robot trajectories through software functions existing in the robots. The method is tested on KUKA robots in the laboratory at Chalmers University of Technology in Sweden and in the laboratories in the German companies KUKA Robotics GmbH and Daimler AG. The optimization results reduced up to 30% of energy consumption and up to 60% in peak power.

For instance, in a typical body shop, over 300 robots assemble roughly 200 to 400 parts using a total of 2500 to 4000 spot welds before they are dispatched to the paint shop [13]. An average of 180-kg-

payload body shop robot consumes energy of about 8 MWh in a year [14] and robots overall consume approximately 8% of the total electrical energy in production processes.

A study on weld body where body in white is obtained through the assembly of approx. 200 to 500 panels and blanks. Now a days automobile industry have moved towards model mix. It means production of different models or variants at same assembly line through flexible and reconfigurable multi-robot cells [15, 16]. It increases product flexibility in terms of new model and reduces production cost [17, 18]. A unified methodology, aiming at optimizing the holistic cell design and motion planning reduces design time and errors. Now a days the methods are integrated into a computerized approach which has the potential to accelerate the whole cell design and motion planning processes which reduces human efforts [19].

The problem of effective motion planning for industrial robots are seen at present for which trajectory of manipulator is optimized using the principle of interpolation in the configuration or Cartesian space [20].

The implementation of lean manufacturing strategy allows strengthening the phase sequence that leads to excellence in operation and a continuous improvement in the non-value added activities. Thus, the impact of lean practices pays substantially with the operating performance of plants and use of lean tools allows the improvement of results. The tool kaizen is applied as a way to progress toward lean manufacturing. It has been gradually adopted as a potential solution for many organizations, particularly within the automotive and aerospace industrial areas.

A study of the complexity of programming which is one of the major hurdles, preventing automation using industrial robots for small to median enterprises (SMEs) [21] is done. The solution to such problem is a comprehensive review of the recent research progresses on the programming methods for industrial robots, including online programming, offline programming (OLP) [22], and programming using Augmented Reality (AR) techniques. Different online programming softwares are listed in the table below:

Table 1 Online Programming software package

	Software/ Ref	Company/Feature
Generic Robotics Software	Delmia (IGRIP, ENIVISION); Kineo, CENIT; [23]	Dassault Systems; VR
	Rob CAD (Emworkplace) [24][25]	Technomatix; VR
	Robomaster	Robomaster
	Robsim; [26]	Camelot
	Workspace 5	Wat Solutions
	Cosimir	Festo
Robotics Software from Robot Manufactures	RobotStudio	ABB: Most Popular
	MotoSim	Motoman
	KUKA-SIM, CAMrob;[27]	KUKA
	Roboguide	Fanuc
	Wincaps III	Denso
	D STUDIO	Staubli
	MELFA WORKS	Mitsubushi
	Pc-ROSET	Kawasaki
	AX on Desk	Nachi
Academic/ Open Source Robotics Software	[28]	Various MATLAB based Software
	[29]	Aristotles University of Thessaloniki, Greece; Based on Solidworks
	[30]	Orebro University, Sweden; Based on standard CAD
	[31]	Based on AutoCAD, Autolisp
	PIN [32]	European Centre for Mechatronics, Open GL based macro programming
	ROBOMO [33]	Open GL
	[34,35]	Daegu University, Korea; VRML' Tribbon
	RoBott	University of Minho, Portugal; OOP Java

A methodology for collision free trajectory and coordination optimization of cyclic multi-robot systems, both velocity tuning and time delays are used to coordinate the robots that operate in close proximity and avoid collisions. This methodology can be demonstrated for productivity/smoothness

optimization, and for energy conservation. It can also be verified for Multi-stage tandem sheet metal press line of an automobile industry [36].

The traditional manual path planning processes are less efficient, and can not guarantee optimality. To obtain shortest collision free welding paths GA, PSO and improved GA-PSO algorithms are used which results in terms of no. of iteration, error, strong searching ability and practicality [37].

Figure 2: Pictorial view of Multi robot spot welding process

Ant Colony Optimization Algorithm (ACO) can be used as a heuristic algorithm for computing Travelling salesman problem (TSP) in terms of convergence speed and the ability to finding better solutions [38].

Overarching objective of investigating the use and impact of manufacturing productivity improvement approaches within automotive component suppliers has the specific aims of identifying (i) the level of understanding and use of continuous improvement tools and management methodologies within organisations and (ii) the factors which could contribute to them failing to achieve the results

expected. A survey of 161 automotive suppliers investigated all elements of selection, training and implementation of tools and methodologies. The adoption of continuous improvement tools and methodologies is widespread and discusses the relatively high failure rates. The reasons which may contribute to failure are lack of suitable resources, lack of understanding and training within senior personnel and a non-strategic approach to the application of tools and methodologies.

Industrial robots should perform complex tasks in the minimum possible cycle time in order to obtain high productivity. The problem of determining the finest way of a manipulator's end effector visiting a number of task points is identical to the well-known travelling salesman problem (TSP).The travel time between any two points is significantly affected by the choice of the manipulator's configuration. Therefore, the multiple solutions of the inverse kinematics problem should be taken into consideration. A method is introduced to determine the optimal arrangement of task points visited by the tip of the end effector of an articulated robot and it can be applied to any non-redundant manipulator. This method is based on genetic algorithms and an innovative encoding is introduced to take into account the multiple solutions of the inverse kinematic problem. The results show that the method can determine the optimal arrangement of a substantial number of task points for machines up to six-degrees of freedom.

The productivity enhancement by setup time reduction in a fagor press involved in the machining of evaporator plates is possible. The well-known Single Minute Exchange of Die technique (SMED) is applied for the purpose. SMED is one of the many lean manufacture methods for minimizing waste in a manufacturing process. It provides a quick and effective way of altering a manufacturing process from running the current product to running the next product. Using SMED technique, the tool change over time was reduced from 40 minutes to 12.

Some problems and challenges of an automobile company engaged in assembling car rear window are faced. The whole assembly line agonizes due to the absence of recognized standard time for actions carried out by operatives, the non-value-added activities involved and the inefficient methods such as unplanned aisle and manual screwing, and walking distance, material wastages and imbalance in the material flow. In Maynard Operation Sequence Technique (MOST), through the process flow and process

redesign analysis, workflow and material handling are improved. Therefore, it has been possible to reduce the production cycle time to supply the higher level of demand with shorter takt time maintaining the current level of manpower.

In recent manufacturing system the most important parameters in production line are work in process, takt time and line balancing. Lean tools and techniques can be implemented to reduce the cycle time. From the initial time study the bottleneck processes were identified and then necessary processes were also identified for the bottleneck process. Afterward the advance actions have been established and applied using different lean tools like value stream mapping, line balancing and 5S. Various problem areas are identified using current value stream mapping, which is also able to describe the existing status. To reduce the process cycle time and unnecessary movements of man and material, 5S method is used. The improvement activities were implemented with required suggested and the future state value stream mapping was developed. From the results it was concluded that the total cycle time was reduced about 290.41 seconds and the customer demand has been increased about 760 units.

For series of point-to-point type movements method of asynchronous motion profile smoothening using cubic B-spline interpolation, A synchronized FLY-BY in Joint space method is most suitable for optimization of existing robot programs for handling or welding applications that use the point-to-point movement commands [39].

Increase in sales volume has evolved by improving overall equipment effectiveness (OEE) of machines, plant productivity and production cost through total productive maintenance (TPM). It is observed that OEE and productivity are closely linked together and improvement in OEE contributes in enhancing plant productivity. It also summarizes that OEE is not the only productivity improvement criteria whereas capacity building through improvement projects or technology up gradation with capital investment also contributes in escalating productivity. This study is based on a tractor company (20 to 75 HP), light machine shop situated in Punjab.

Product sequencing and batch policies have a significant impact on product quality. How to determine an appropriate sequence or batch policy? How to select the optimal sequence with respect to quality? Will the quality characteristics change under different policies? In automotive assembly plants, it is now typical that multiple models of vehicles with more options (model mix.) can be made on the same production line. In automotive paint shops, although painting booths are typically capable of painting different colors, the paint quality is strongly correlated to the number of available paint colors [40] and it may temporarily decline after color change [41]. The flexibility study focuses on flexibility measurement, investment cost, scheduling and tradeoffs between productivity and flexibility, etc. [42-48].

Heuristic algorithms are used in [49] to consider batch scheduling problem by minimizing setup costs and the mean flow time. Authors [50-52] address car sequencing problem to minimize color changes. Similarly, re sequencing at a color batching process in an automotive paint shop is analyzed [53].The re- sequencing problem with limited flexibility and sequence-dependent changeover costs is studied by few researchers [54, 55]. In these studies, the goals are to reduce changeover costs rather than improving quality.

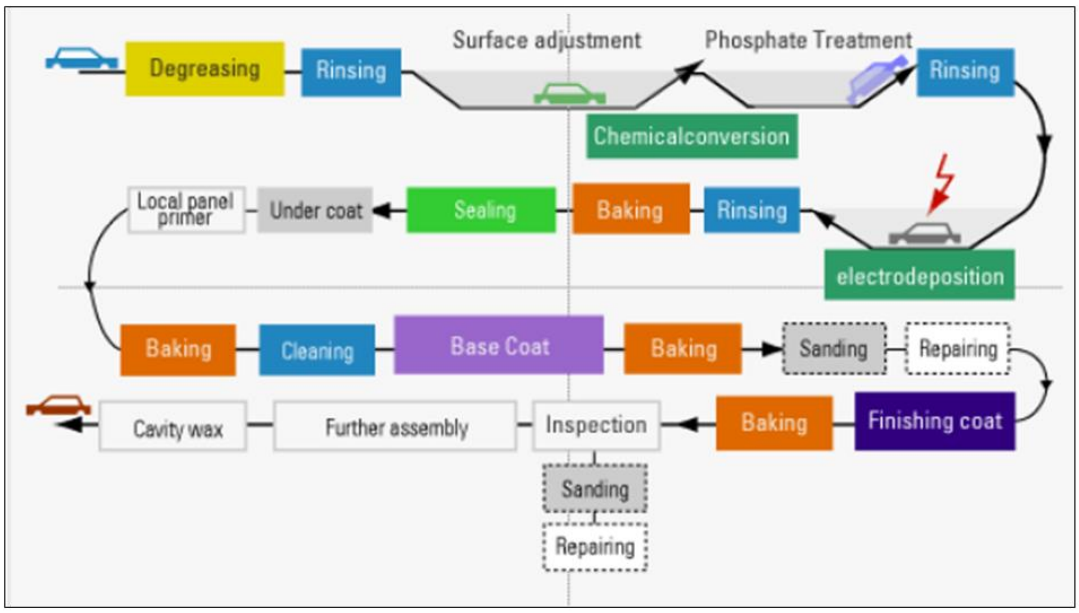


Figure 3: Overview of Painting Process

A study on assembly line of an automotive company with the aim of identifying and minimizing the bottlenecks, and improving the productivity by standardizing the work method and time, maximizing the utilization of resources as well as changing the conventional tools [56]. This study is based on assembly of doors of an automobile body using Maynard Operation Sequence Technique (MOST).

Gaps in the Existing Literature

There is no extensive study done on futuristic trends of automobile industry and how it is going to impact the present industry hence this needs to explore in depth. Identifying factors improve productivity and remove bottlenecks needs to be researched.

Welding is an essential part of manufacturing industry, and welding robots are widely used to decrease costs, improve quality and increase productivity. Existing simulation tools such as Rob cad, IGRIP or Catia are unable to solve the problem of optimal robot motion planning. Existing literature gives methods based on the *Rob cad* simulation model which are less feasible for real robotic work cell to give our proposal an insight. We have selected spot welding robots which are widely used in four wheeler manufacturing.

To find a reasonable path of spot welding robot we propose a MATLAB based program. We can compare convergence rate of solution of TSP with different evolutionary techniques. A solution for around 20 points of spot welding cells are provided by soft computing techniques. It can be extended to optimize hundreds of welding easily.

Here we propose an approach in which we will optimize the trajectory of spot welding manipulator by using evolutionary techniques like GA, GESA and PSO etc. With this approach trajectory of robot can be optimized which will minimize the distance travelled by the robot and reduce energy consumption in manufacturing process.

One can optimize the holistic cell design by applying MOST (Maynard Operational Sequence Technique) to minimize cycle time of station. A research study with the application of the MOST can be explored from a wider perspective through implementation in a single or mixed model assembly lines having large number of work stations.

Production Planning and Control (PPC) department of automobile companies are least concern towards color change frequency while generating Vehicle Build Sequence. They never make a plan according to paint shop instead they make a plan as per the need of market. We propose colour grouping by introducing a new station before finishing coat to minimize color changeover cost and improving productivity of paint shop.

A lot of scope exists in identifying features that contribute to manufacturing, operational and capacity flexibility in automobile industry.

Chapter III: Research Proposal

3.1 Research Question

a) Is it possible to predict futuristic trends and salient features of automobile industry?

b) Is it possible to apply concepts of flexible manufacturing to enhance productivity in automobile industry?

3.2 Research Objectives

The objective of this research work is to meet the increasing demand of automobile industries by enhancing the productivity with minimum capital investment. In this work, the need for optimizing the welding path of robots, paint and assembly will be focused. This will further make manufacturing economical and has competitive edge over the various players of manufacturing in the automobile industries.

Companies will be able to highlight the bottleneck areas, the key business issues and then apply appropriate tools and optimization techniques to achieve enhanced productivity. Minimize wastage of resources using delay time analysis on automated line. Optimization of robotic arm/manipulators path in focused areas to help in eliminating non-value added activities that can result in improving the productivity.

The objective envisages can be detailed as below:

1. Study of futuristic trends in automobile industry.
2. Explore the factors affecting productivity of an automobile industry.
3. Determine bottleneck areas of an automobile industry by line stoppage/breakdown analysis or delay time analysis.
4. Eliminating welding bottleneck areas by optimization of robotic arm/manipulators path in focused areas by using soft computing techniques.
5. Study of painting bottleneck areas by introducing a new station before finishing coat to minimize color changeover cost and improving productivity of paint shops.
6. Reducing bottleneck areas of weld and vehicle assembly by applying MOST (Manyard Operational Sequence technique) which results in reduction of operator fatigue.
7. Study of salient features of manufacturing flexibility, Operational flexibility, capacity flexibility in automobile industry.

3.3 Pilot Study

A pilot study shown in table 2 is done to find non value added activity by MOST analysis on a mixed model weld assembly line to find bottleneck areas and will be extended to various aspects of the present work.

Table 2: MOST calculation sheet for identifying bottleneck operations

LINE NAME:- U/B	PROCESS	member component ,dash fitment on JIG(2341)and JIG(2311)	MODEL:- A	DATE						LINE TACT TIME
				2017	Y	8	M	15	D	Seconds
CODE L-4	14									57.00

No.	OPERATION DETAILS / PART NO / PART NAME	SEQUENCE MODEL	FREQ	TMU / 0.8 FAC / SEC
1	walk 5 steps, bend 50%, grasp, place with adjustment on Jig	A 10 B 3 G 1 A 10 B 0 P 3 A 0	1	270.00 / 216.00 / 7.78
2	with in reach , readjust (take 10% , does not occure every time)	A 0 B 0 G 0 A 1 B 0 P 3 A 0	1	40.00 / 32.00 / 1.15
3	with in reach, **tilting the object**, walk one step , place with adjustment	A 1 B 0 G 3 A 3 B 0 P 3 A 0	1	100.00 / 80.00 / 2.88
4	**walk four step** , pick a panel dash lower side with R.H.,put in L.H.	A 6 B 0 G 1 A 1 B 0 P 1 A 0	1	90.00 / 72.00 / 2.59
5	walk four step, Pick assembly, walk four step , placement with adjustment on JIG(2341)	A 6 B 0 G 1 A 6 B 0 P 3 A 0	1	160.00 / 128.00 / 4.61
6	already getting panel dash lower side place it on JIG.	A 0 B 0 G 0 A 1 B 0 P 3 A 0	1	40.00 / 32.00 / 1.15
7	walk 2 step, inspect the fittment of component on JIG on GOT.	A 0 B 0 G 0 A 3 B 0 P 0 T 1 A 0 B 0 P 0 A 0	1	40.00 / 32.00 / 1.15
8	Walk back two step ,readjust (take 10% ,does not occure every time)	A 3 B 0 G 1 M 3 X 0 I 0 A 0	1	7.00 / 5.60 / 0.20
9	walk 2 step, grasp,switch on.	A 3 B 0 G 1 M 1 X 0 I 0 A 0	1	50.00 / 40.00 / 1.44
10	walk 5 steps, bend 50%, get bracket suspension upper and panel comp. front apron L.S. from right hand and place it on L.H.	A 6 B 3 G 1 A 1 B 0 P 1 A 0	2	180.00 / 144.00 / 5.18
11	get extension appron from L.H.	A 1 B 3 G 1 A 0 B 0 P 0 A 0	1	50.00 / 40.00 / 1.44
12	**walk 4 step** , place all these three component with adjust.on JIG(2311)	A 0 B 0 G 0 A 6 B 0 P 3 A 0	3	150.00 / 120.00 / 4.32
13	with in reach, inspect the fittment of component on JIG on GOT.	A 0 B 0 G 0 A 1 B 0 P 0 T 1 A 0 B 0 P 0 A 0	1	20.00 / 16.00 / 0.58
14	walk 1 step, grasp,switch on.	A 3 B 0 G 1 M 1 X 0 I 0 A 0	1	50.00 / 40.00 / 1.44
	Individual Component Times OF SHEET		TMU	SUM 1247.00
				SUM 997.60
			Sec	SUM 35.91

3.4 Plan of work

Time Line		2020				2021				2022			
S.no	Activity Description	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1	Study of futuristic trends in automobile industry												
2	Report preparation and publications												
3	Explore the factors affecting productivity of an automobile industry												
4	Report preparation and publications												
5	Determine bottleneck areas of an automobile industry by line stoppage/breakdown analysis or delay time analysis.												
6	Reverification, report preparation and publications												
7	Eliminating welding bottleneck areas by optimization of robotic arm/manipulators path in focused areas by using soft computing Techniques.												
9	Study of painting bottleneck areas by introducing a new station before finishing coat to minimize color changeover cost and improving productivity of paint shops												
10	Post implementation monitoring,reverification,report preparation and publications												
11	Reducing bottleneck areas of weld and vehicle assembly by applying MOST (Manyard Operational Sequence technique) which results in reduction of operator fatigue.												
12	Post implementation monitoring,reverification,report preparation and publications												
13	Report on salient features of manufacturing flexibility, Operational flexibility, capacity flexibility in automobile industry.												

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